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ABSTRACT

This module introduces the physical, biological, and chemical constituents of wastewaters and sludges which are of concern in land treatment systems. The characteristics of typical municipal wastewater are tabulated for strong, medium, and weak sewages. Some of the factors affecting pollutant concentrations are listed. Flow, distribution and expected removals of various waste constituents in conventional treatment systems are illustrated through the use of flow diagrams. Since the liquid effluent or sludge from various conventional pretreatments, as well as raw wastewater, may be the influent to a land application site, this information is necessary to the design of land treatment schemes. A summary of flow distribution and pollutant removals in land treatment systems is presented in a script written to accompany a slide presentation. (Author/BB)

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ED162822

# Land Application of Wastes

An Educational Program

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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WASTE CHARACTERISTICS
Module 5
January, 1978

SE 025 019

# LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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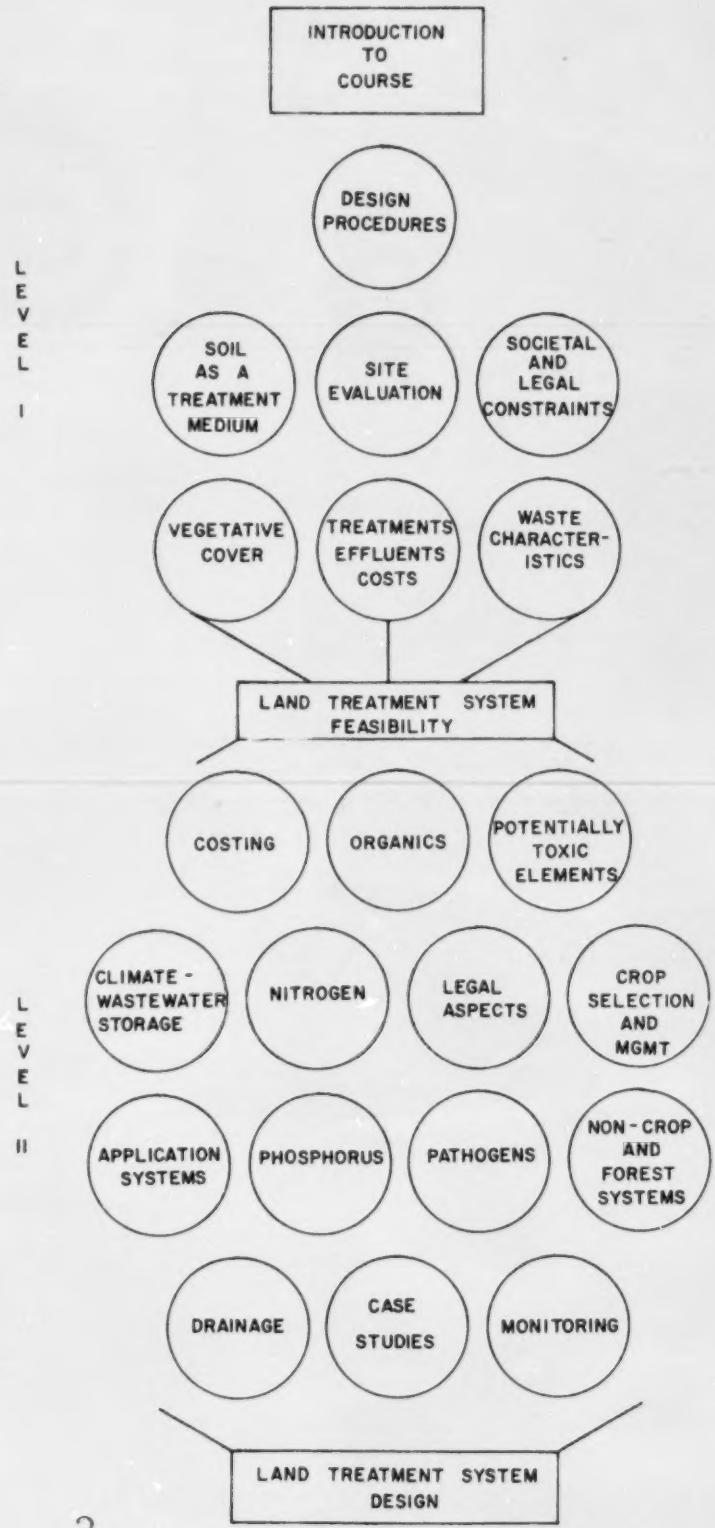

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WASTE CHARACTERISTICS

Module 5

January, 1978

## Summary

This module introduces the physical, biological, and chemical constituents of wastewaters and sludges which are of concern in land treatment systems. The characteristics of typical municipal wastewater are tabulated for strong, medium, and weak sewages. Some of the factors affecting pollutant concentrations are listed.

"Waste Characteristics" is a Level I module, therefore other modules are referenced for more detailed information on organic matter content, nutrients, pathogens, and potentially toxic elements. Flow, distribution and expected removals of various waste constituents in conventional treatment systems are illustrated through the use of flow diagrams. Since the liquid effluent or sludge from various conventional pretreatments, as well as raw wastewater, may be the influent to a land application site, this information is necessary to the design of land treatment schemes. For a summary of flow distribution and pollutant removals in land treatment systems, see the A-T lesson for this module.

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## Glossary

$BOD_5$ - Five day biochemical oxygen demand. A measure of the amount of dissolved oxygen required to meet the metabolic needs of aerobic microorganisms which assimilate the organic matter available to them in a water sample. Performed with microorganisms acclimated to the sample material, for five days at 20°C.

COD - Chemical oxygen demand. A measure of the organic matter in a sample which is subject to oxidation by a strong chemical oxidant under standard laboratory conditions. The oxygen consumed in the process is actually measured.

filterable solids - That portion of the solids content of a water sample which will pass through a filter, and not be volatilized by drying of the collection vessel. Also called "filtrable residue".

MPN - Most probable number. A statistical analysis of bacterial concentration in a water sample.

PFU - Plaque-forming unit. A virus or viruses which forms a colony visible as a clear area on a plate of host cells. Used as a measure of viral concentration.

septic - Characterized by anaerobic breakdown of proteins by certain bacteria, resulting in foul-smelling end products.

suspended solids - That portion of the solids content of a water sample which will not pass through a filter. Also called "non-filtrable residue."

TOC - Total organic carbon. A measure of carbon contained in organic constituents of a water sample.

## Objectives

Upon completion of this module, the participant should be able to:

1. List the major waste characteristics of concern to land treatment.
2. Name the waste constituent which usually is most limiting in land treatment design.
3. State the range of values of the following waste constituents in typical municipal sewage: Total solids, total nitrogen, total phosphorus, $BOD_5$, and COD.
4. State the major constituents of concern to land treatment of sludge.

## Introduction

In the evaluation and design of waste treatment alternatives, the constituents of wastes play a leading role. Some of these waste constituents present aesthetic problems while others are harmful to living organisms. This module presents a summary of data on the waste characteristics of common wastewaters and sludges, and briefly examines their fate in conventional treatment and land application systems.

The application of wastes to the land for treatment and/or disposal has received renewed emphasis in waste treatment technology. Land treatment of wastes is often an economically feasible alternative. However, this alternative requires the designer to mesh his design with an existing ecosystem. In doing this, he must be careful not to alter adversely 1) the biota within the soil/plant treatment medium, 2) the physical structure of the soil profile, or 3) the surface or groundwater quality beyond acceptable limits.

In order to determine the feasibility of land application of waste, the limiting rate of application of the controlling pollutant(s) must be correlated with the capacity for treatment of the soil/plant system. The information in this module, combined with Module 3 "Soil as a Treatment Medium", will assist in identifying the potential limiting factors and enable the comparison of pollutant conversion and removal efficiencies with those potentially available in land application systems.

## Wastewater Characteristics

The number of waste characteristics, each having broad variability, emphasizes the complexity found in wastes, and the required flexibility demanded of treatment processes. This variability is due to the diverse sources of wastes, i.e., municipal, industrial, and agricultural sources, as well as the differing activities within each major source. Only typical municipal wastewater and sludges will be treated here.

### Typical Untreated Municipal Wastewater Characteristics

A necessary preliminary step when planning for a land application system, as with any other waste treatment system, is a detailed evaluation of the waste characteristics. These waste characteristics are often divided into three major categories - physical, biological, and chemical. Table 1 displays those characteristics which are usually documented for conventional waste treatment.

Characteristics of typical municipal wastewaters and sludges are outlined. They can be broken down into physical, biological and chemical categories.

### Variations in Municipal Wastewaters

The variations found in municipal wastewaters are due to many different things, some of which include 1) population size and industrial distribution, and 2) combined vs. separate storm and sanitary sewers. The figures in Table 1 do not express any of the extreme variations suggested in 1) & 2) above, but only those constituents typically found in sanitary sewer systems.

Population vs. industrial distribution In general, as population sizes increase, so do industrial facilities. Industrial loadings into municipal systems could easily project any one of the constituents in Table 1 to many times more than that shown. However, pretreatment of industrial wastes

Industrial discharges can affect waste characteristics greatly.

Table 1.

Typical Municipal Wastewater Characteristics - Untreated
(mg/l except where noted)

| | Strong | Medium | Weak | Reference* |
|---|---|---|---|---|
| **Physical Characteristics** | | | | |
| Color (nonseptic) | Gray | Gray | Gray | 1 |
| Color (septic) | Gray-Black | Blackish | Blackish | 1 |
| Odor (nonseptic) | Musty | Musty | Musty | 1 |
| Odor (septic) | Musty-$H_2S$ | $H_2S$ | $H_2S$ | 1 |
| Temperature-°F (average) | 55°-90° | 55°-90° | 55°-90° | 1 |
| Total solids | 1200 | 700 | 350 | 2 |
| Suspended solids | 350 | 200 | 100 | 2 |
| Fixed | 75 | 50 | 30 | 2 |
| Volatile | 275 | 150 | 70 | 2 |
| Filterable solids | 850 | 500 | 250 | 2 |
| Fixed | 525 | 300 | 145 | 2 |
| Volatile | 325 | 200 | 105 | 2 |
| **Biological Characteristics** | | | | |
| Total coliforms (MPN/100 ml) | $100x10^6$ | $30x10^6$ | $1x10^6$ | 2 |
| Virus (PFU/l) | 7000 + | | 200 | 4 |
| **Chemical Characteristics** | | | | |
| pH | 8.0 | 7.5 | 6.5 | 1 |
| Total nitrogen | 60 | 40 | 15 | 1 |
| Organic nitrogen | 19 | 15 | 5 | 1 |
| Ammonia nitrogen | 40 | 25 | 10 | 1 |
| Nitrate nitrogen | 1.0 | 0.5 | -- | 1 |
| Total phosphorus | 20 | 10 | 6 | 1 |
| Organic phosphorus | 5 | 3 | 2 | 2 |
| Inorganic phosphorus | 15 | 7 | 4 | 2 |
| $BOD_5$ (20°C) | 300 | 200 | 100 | 2 |
| COD | 1000 | 500 | 250 | 2 |
| TOC | 300 | 200 | 100 | 2 |
| Chlorides | 100 | 50 | 30 | 2 |
| Toxic elements (concentrations found in residential trunk sewers) | | | | |
| Cadmium | | 0.007-0.019 | | 3 |
| Chromium | | 0.008-0.09 | | 3 |
| Copper | | 0.12 -0.21 | | 3 |
| Lead | | 0.075-0.12 | | 3 |
| Nickel | | 0.014-0.09 | | 3 |
| Zinc | | 0.200-0.25 | | 3 |

*1. Battelle Memorial Institute, Final Report 1974.

2. Metcalf & Eddy, 1972. 3. J.A. Davis III, 1975.

4. E. DeMichele, 1974.

are usually required for incompatable substances prior to discharge into municipal systems. Discharge of potentially toxic elements from industrial sources can be an important area in which pretreatment is necessary.

Combined vs. separate storm and sanitary sewers

Some towns and cities have a combination of storm and sanitary sewers. A summary of sewage characteristics for fifteen of these cities is shown in Table 2. The most noticeable affects that combined systems have on untreated wastewater is the increased flows (not shown in Table 2) and the increase in suspended solids. The initial surge of storm water runoff carries the greatest percentages of organic and mineral solids and creates serious problems for all waste management systems. Once this washdown has occurred, subsequent runoff is relatively clean. Often these surge flows by-pass the treatment facility because of the inability of the treatment processes to handle the excessive volumes of water. Although all recent collection system designs require the separation of storm water flows, many combined systems are still in use.

Combined storm and sanitary sewers are still in use in many older systems. Major effects are to produce shock hydraulic loads and greatly increase suspended solids.

Table 2

Comparison of Quality of Combined Sewage for Various Cities (J. A. Lager, 1974)

| Type of Wastewater<br>Location, Year | $BOD_5$ mg/1 | | COD mg/1 | | DO mg/1 | SS mg/1 | | Total Coliforms MPN/100 ml | | Total Nitrogen mg/1 as N | Total Phosphorus mg/1 as P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | Range | Avg | Range | Avg | Avg | Range | Avg | Range | Avg | Avg |
| Typical untreated municipal (separate system) | 200 | 100-300 | 500 | 250-750 | - - | 200 | 100-350 | $5x10^7$ | $1x10^7$-$1x10^9$ | 40 | 10 |
| Typical treated municipal (separate system) | | | | | | | | | | | |
| Primary effluent | 135 | 70-200 | 330 | 165-500 | - - | 80 | 40-120 | $2x10^7$ | $5x10^7$-$5x10^8$ | 35 | 7.5 |
| Secondary effluent | 25 | 15- 45 | 55 | 25- 80 | - - | 15 | 10- 30 | $1x10^3$ | $1x10^2$-$1x10^4$ | 30 | 5.0 |
| Selected combined | | | | | | | | | | | |
| Atlanta, Ga. 1969 | 100 | 48-540 | - - | - - | 8.5 | -- | - - | $1x10^7$ | - - - - | -- | 1.2 |
| Berkeley, CA. 1968-69 | 60 | 18-300 | 200 | 20-600 | - - | 100 | 40-150 | - - | - - - - | -- | - - |
| Brooklyn, NY 1972 | 180 | 86-428 | - - | - - | - - | 1051 | 132-8759 | - - | - - - - | -- | 1.2 |
| Bucyrus, Ohio 1968-69 | 120 | 11-560 | 400 | 13-920 | - - | 470 | 20-2440 | $1x10^7$ | $2x10^5$-$5x10^7$ | 13 | 3.5 |
| Cincinnati, O. 1970 | 200 | 80-380 | 250 | 190-410 | - - | 1100 | 500-1800 | - - | - - - - | -- | - - |
| DesMoines, Iowa 1968-69 | 115 | 29-158 | - - | - - | - - | 295 | 155-1166 | - - | - - - - | 12.7 | 11.6 |
| Detroit, Mich. 1965 | 153 | 74-635 | 115 | - - | - - | 274 | 120-804 | - - | - - - - | 16.3 | 4.9 |
| Kenosha, Wis. 1970 | 129 | -- -- | 464 | - - | - - | 458 | - - | $2x10^6$ | - - - - | 10 | 5.9 |

TABLE 2 -- Continued

| Type of Wastewater<br>Location, Year | $BOD_5$ mg/l | | COD mg/l | | DO mg/l | SS mg/l | | Total Coliforms MPN/100 ml | | Total Nitrogen mg/l as N | Total Phosphorus mg/l as P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | Range | Avg | Range | Avg | Avg | Range | Avg | Range | Avg | Avg |
| Milwaukee, Wis.<br>1969 | 55 | 26-182 | 177 | 118-765 | - - | 244 | 113-848 | - - | $2x10^5$-$3x10^7$ | 3-24 | 0.8 |
| Racine, Wis.<br>1971 | 119 | - - | - - | - - | - - | 439 | - - | - - | - - - - | - - | - - |
| Roanoke, Va.<br>1969 | 115 | - - | - - | - - | - - | 78 | - - | $7x10^7$ | - - - - | - - | - - |
| Sacramento, CA.<br>1968-69 | 165 | 70-328 | 238 | 59-513 | - - | 125 | 56-502 | $5x10^6$ | $7x10^5$-$9x10^7$ | - - | - - |
| San Francisco, CA.<br>1969-70 | 49 | 1.5-202 | 155 | 17-626 | - - | 68 | 4-426 | $3x10^6$ | $2x10^4$-$2x10^7$ | - - | - - |
| Washington, D.C.<br>1969 | 71 | 10-470 | 382 | 80-1760 | - - | 622 | 35-2000 | $3x10^6$ | $4x10^5$-$6x10^6$ | 3.5 | 1.0 |

## Wastewater Characteristics in the Evaluation and Design of Land Application Systems

In evaluating waste characteristics for land application design, several stand out as having more immediate relevance than others (see Table 3). Experience has suggested that these will generally define the design limitations in land application systems.

### Solids

Solids which generally pass through preliminary treatment are categorized under two major headings, suspended and filterable solids. Figure 1 outlines their relationship. Additional categories have been devised which further separate the settling characteristics and the degree of solubility. Each of these categories has a range of organic and mineral constituents. The approximate percentage of organic and mineral matter (or ash) in medium strength domestic sewage is also shown in Figure 1.

Organics Approximately 50% of the total solids found in municipal sewage are organic. In addition to the predominant human waste organics, these include surfactants (primarily synthetic detergents) and phenols. Trace amounts of pesticides, herbicides, and other home and garden chemicals are also found. Recent legislation has required that pesticides be biodegradable within a specified time limit. It should also be noted here that a list of potentially toxic elements is published by the U.S. Environmental Protection Agency along with strict effluent concentration guidelines. These include several common pesticides. Therefore, future buildup of these organics in the environment is unlikely. Industrial sources can contribute other organic compounds not normally found in domestic wastes.

Approximately 50% of municipal water total solids content is organic, including detergents, phenols and home and garden pesticides, etc.

Table 3

Waste Characteristics in Land Application Systems

- Solids
  - Organics
  - Mineral
- Nutrients
  - Nitrogen
    - Ammonium nitrogen
    - Organic nitrogen
    - Nitrate nitrogen
  - Phosphorus
- Hazardous substances
  - Pathogens
    - Virus
    - Bacteria (1/100 ml to 4/100 ml coliform, testing procedure specific)+
    - Protozoa
    - Helminths
  - Toxic substances - inorganic
    - Arsenic (0.05 mg/1)+
    - Barium (1 mg/1)+
    - Boron*
    - Cadmium (0.010 mg/1)+*
    - Chromium (0.05 mg/1)+
    - Copper*
    - Fluoride (1.4-2.4, temperature dependent)+
    - Lead (0.05 mg/1)+*
    - Manganese
    - Mercury (0.002 mg/1)+
    - Nickel*
    - Nitrate as N (10 mg/1)+
    - Selenium (0.01 mg/1)*+
    - Silver (0.05 mg/1)+
    - Vanadium
    - Zinc*
  - Toxic substances - organic
    - Chlorinated hydrocarbons
      - Endrin (0.0002 mg/1)+
      - Lindane (0.004 mg/1)+
      - Methorychlor (0.1 mg/1)+
      - Toxaphene (0.005 mg/1)+
    - Chlorophenoxys
      - 2,4-D (0.1 mg/1)+
      - 2,4,5-TP Silvex (0.01 mg/1)+

+The groundwater criteria resulting from the land application of wastewater, including the affected native groundwater (R.E. Train, 1974).

*Those most likely to cause toxicity to higher plants in soils where large amounts of domestic sludge are applied over a period of years (A.L. Page, 1974).

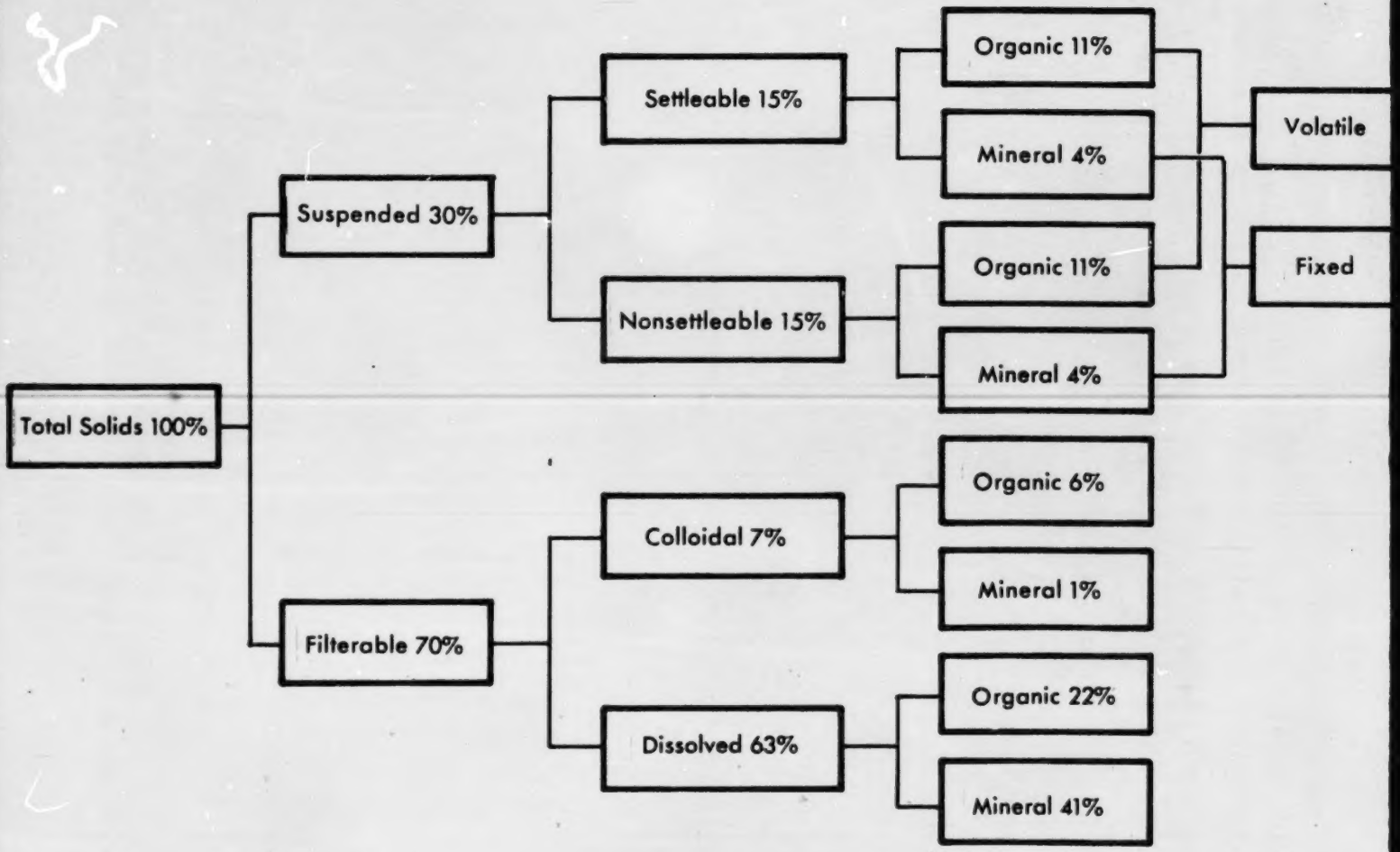


Figure 1. Classification of solids found in medium strength sewage.

Various methods have been devised to determine the organic content of wastewaters. A comparison of these measurements is shown in Figure 2. The five day biochemical oxygen demand ($BOD_5$) is one parameter often seen in wastewater analysis. It determines the oxygen utilized by microorganisms in digesting organics over a 5 day period. It is the most widely used test for the purpose of regulatory control of wastewater treatment processes. Long term BOD analyses provide more information about the oxygen-demanding characteristics of organic matter in a sample. These BOD analyses can be conducted for any period of time necessary to stabilize the sample, and provide useful information on the ultimate carbonaceous oxygen demand. Long-term BOD tests are used to determine the oxidation curve and exponential rate factor which must be known to compute ultimate BOD of a particular waste, given the 5-day BOD result.

Many laboratory analyses exist for determination of organic matter impact in wastewater. For typical municipal wastewater, percentage values can be assumed to compare the various measures.

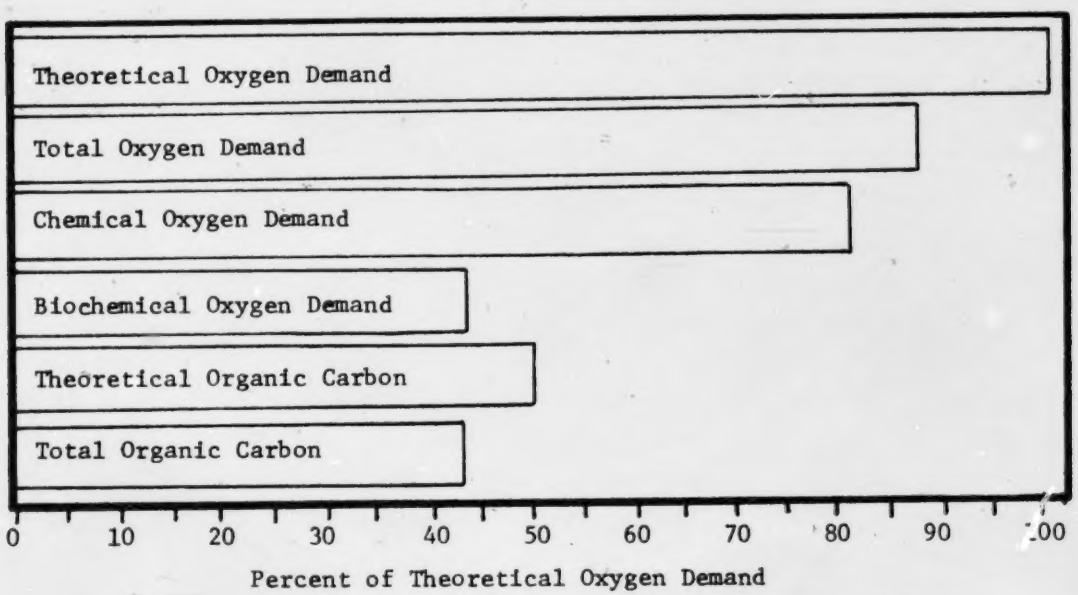


Figure 2. Approximate relationship among measures of the organic content of typical municipal wastewaters.

The chemical oxygen demand (COD) test measures organic matter readily oxidizable by a strong chemical oxidant. Results are available in a matter of hours rather than days, making this test generally more useful for in-plant process control decisions. The theoretical oxygen demand (ThOD), total oxygen demand (TOD), theoretical organic carbon (ThOC), and total organic carbon (TOC) are other test procedures utilized to determine total amounts of organic matter. A more detailed discussion of these testing procedures may be found in Module 17, "Organic Matter" and in standard environmental engineering texts (Metcalf and Eddy, 1972; Sawyer and McCarty, 1974).

Clogging of the soil can result from biological decomposition as well as physical blockage of soil pores by suspended solids in high rate systems.

Decomposition of organics in land application systems must occur within the microbial active zone in the soil profile. The microbial population is dependent upon, among other things, the available organics. The population responds quickly to organic loads on the soil system. In decomposing readily biodegradable organics, the microbes can generate an impermeable layer within the top inch of soil. This biological clogging is a function of the waste organic material added and the pore space in the receiving soil. Data linking organic loading, soil porosity, and clogging suggests that soils have a remarkably high ability to assimilate organics as long as anaerobic conditions are avoided (McGauhey, 1966). This fact emphasizes the importance of avoiding ponding in normal crop irrigation practice and providing resting periods between water applications.

The total suspended solids (TSS) in the waste also has the potential to clog the soil surface. Generally, this parameter can be the cause of initial clogging, especially where the influent to the land application site consists of a high TSS wastewater applied at very high application rates such as those expected in rapid infiltration systems.

Clogging of the soil profile is a real threat in land application systems, especially in those systems receiving large amounts of organics. For this reason, the total suspended solids and the $BOD_5$ or COD should be two waste characteristics monitored in the influent of high rate (> 5 ft/wk) land application systems.

Organics are discussed at length in Module 3, "Soil as a Treatment Medium" and Module 17, "Organic Matter" where additional data on decomposition and soil clogging can be found.

Total dissolved solids (TDS) must conform to groundwater regulations for drinking water supplies, and must be monitored to avoid salts buildup in arid areas.

Minerals The mineral portion of total solids is largely made up of dissolved salts and is commonly called total dissolved solids (TDS). These solids are of interest because of their effect on the groundwater, and the related possibility of degrading drinking and irrigation waters. The Public Health Service has set a preferable limit of 500 mg/l on the total dissolved solids content of drinking waters, but in the most recent standards published by EPA (1976) only specific inorganic constituents are noted. Although many waters used for drinking in the United States exceed the suggested limit considerably, it is a useful goal to observe in wastewater management.

Saline and alkali soils are the result of concentrating salts in the root zone. The continuous application of water containing dissolved solids could result in the buildup of salts and other dissolved solids within the soil profile in areas where the evapotranspiration rate is significant. This buildup of salts in the soil solution can deter crop growth (see Module 20, "Crop Selection and Management"). Salt buildup may be avoided by including a leaching factor in the irrigation water requirements. This type of management practice will avoid dissolved solids buildup in the soil solution. However, those solids will be concentrated as water is utilized through evapotranspiration. This more concentrated soil solution will pass through to the groundwater. Where TDS content of the wastewater is less than that of the groundwater, a rapid infiltration/percolation system may be desired for groundwater dilution purposes.

As Table 1 indicates, the total dissolved solids content of municipal wastewater generally lies between 250 and 850 mg/l for weak and strong wastewaters, respectively. A salt (NaCl) concentration of 640 mg/l will result in an electrical conductivity of 1 mmho/cm (25°C). The electrical conductivity of weak and strong municipal wastewaters should be approximately .39 to 1.33 mmho/cm which is comparable to many irrigation waters presently used in the irrigated western United States (Table 4). As is true with these

Table 4

Total Dissolved Solids Content of Selected Irrigation Waters and Irrigation Return Flows

| | California | | Texas[3] | |
|---|---|---|---|---|
| | Imperial Valley[1] | San Joaquin Valley San Luis Drain[2] | High Plains | Low Plains |
| Electrical Conductivity at 25°C. (mmho/cm) | 1.4 | 11 | 1.1 | 2.2 |
| pH | 8.1 | -- | 7.9 | 7.5 |
| Total Dissolved Solids (mg/l) | 915 | 7,000 | 627 | 1,360 |
| Calcium | 104 | 300 | 68 | 92 |
| Magnesium | 35 | 200 | 47 | 67 |
| Sodium | 143 | 1,500 | 36 | 217 |
| Potassium | 5 | 20 | 7 | 4 |
| Carbonate | 0 | -- | 0 | 0 |
| Bicarbonate | 187 | 200 | 309 | 425 |
| Sulfate | 356 | 3,000 | 50 | 262 |
| Chloride | 143 | 1,200 | 134 | 244 |
| Nitrate | 1 | -- | 2 | 11 |

1. A. J. MacKenzie, 1972.
2. L. A. Beck, 1972.
3. C. W. Wendt, 1972.

irrigation waters, management is the key to success. It must be stressed that the salt concentration in municipal wastewater is generally acceptable for crop irrigation. The buildup of salts in the soil solution is a danger, but management techniques are available to deter this buildup. The total dissolved solids content of the wastewater as well as that of the soil solution (or leachate, whichever is limiting) must be known in order to use this management tool.

## Nutrients

Nutrients found in wastewaters that have caused concern include nitrogen and phosphorus. These are essential nutrients for crop production. However, when the amounts available exceed the demand, leaching of these nutrients may occur to ground and surface waters. A major concept throughout this course will be on the design of systems based on the pollutant which causes the strictest limitation. Nitrogen is clearly the most common limiting waste constituent for land application in both wastewaters and most organic sludges. For a given waste, this means that the greatest land area will most often be required based on the nitrogen present in that waste.

For most wastewater, nitrogen places the most severe limitation on land treatment capacity.

Nitrogen Nitrogen in wastewater may be present as ammonium ($NH_4^+$), organic nitrogen (N-org or R-$NH_2$) and nitrate nitrogen ($NO_3^-$) (see Table 1). These three forms should be determined when evaluating a waste for land application. Ammonium and organic nitrogen are usually the principal forms found in raw sewage. However, in a nitrified effluent such as that of secondary effluent as well as some tertiary effluents, nitrate nitrogen ($NO_3^-$-N) increases in quantity. Nitrogen in the ammonium form ($NH_4^+$) will usually adsorb to the negatively charged soil, but nitrate is soluble and will move with the soil water. Movement of this nutrient-enriched soil water within the root zone is necessary to supply nutrients and water to the vegetative crop. Where excesses of nitrogen are applied, the potential of causing nitrogen accumulations in the groundwater exists. Module 15, "Nitrogen Considerations", deals more specifically with nitrogen compounds, their distribution in the environment, and estimates for loading rates based upon nitrogen limitations.

Phosphorus Phosphorus in wastewater occurs mainly as inorganic compounds, primarily $PO_4^{+3}$, and is normally expressed as total phosphate. One of the primary reasons why land application of wastes is becoming a more viable treatment alternative is the soil's high capacity to remove and hold large quantities of phosphorus. In general, it will be shown in Module 19, "Phosphorus Considerations" that phosphorus is seldom a limiting factor in the design of land application systems. The mean annual per capita excretion of phosphorus is approximately 1.2 lbs. Another 2.3 lbs per capita is contributed annually from synthetic detergents (Black & Veatch, 1971). Therefore, domestic sources of phosphorus contribute approximately 3.5 lbs per capita per year. Table 1 indicates typical phosphorus concentrations of 6 to 20 mg/l found in municipal wastewaters. However, when phosphorus concentrations exceed 10 mg/l, it can be assumed that commercial and industrial sources are present.

The soil has a great capacity for tying up phosphorus in wastes.

Usual forms of inorganic phosphorus found in municipal wastewaters include orthophosphate and polyphosphate. Orthophosphates ($PO_4^{+3}$, $HPO_4^{-2}$, $H_2PO_4^{-1}$, and $H_3PO_4$) are immediately available for biological use whereas polyphosphates must first undergo hydrolysis prior to biological use. At times, hydrolysis can be quite a slow process. Organic phosphorus is normally found in higher concentrations in industrial wastes and domestic sewage sludges.

In assessing the maximum application rate of a phosphorus-containing waste, total P is probably the most reliable index. The biological and chemical processes in the soil will tend to convert most of the phosphorus to orthophosphate by hydrolysis of the organic and condensed forms. It is the behavior of orthophosphate that determines the maximum lifetime of a site regarding its ability to retain added phosphorus.

## Hazardous Substances

There are many pathogenic microorganisms and hazardous chemicals which are discharged through municipal sewer systems. Although these substances are relatively dilute in the untreated wastewater, treatment processes including land application systems, tend to concentrate toxic materials. This initially occurs in waste sludges and finally in the soil profile. Because of the fact that many hazardous materials are present and they may be concentrated, they still pose a threat to society. A rational basis for their control must be developed in any waste management scheme. Data presented in Modules 11, "Potentially Toxic Elements", and 9, "Pathogens" will show that the public health dangers due to such contaminants as pathogens and heavy metals can be minimized in land application systems.

Pathogens Many viruses are found in municipal sewage. More than 70 new enteric viruses have been identified in raw sewage over the past 25 years, all of which are found in human feces. The effective (infection-producing) dose rate of virus organisms was thought to be as high as a million but recent studies have shown that one virus particle may cause an infection in the host. While this individual may not develop a clinical disease, he may unknowingly become a carrier (McDermott, 1975).

Pathogenic forms of viruses, bacteria, protozoa, and helminths are found in domestic wastewater.

Pathogenic bacteria are also discharged into domestic wastewaters through the feces of infected humans. Although most disease causing organisms can be found, the concentrations are low, and many are therefore difficult to isolate. For this reason, an indicator organism (usually coliform bacteria) is used to determine if the environment will support pathogenic bacteria populations. Table 1 indicates the amounts of total coliform bacteria and virus expected in typical raw domestic sewage.

Pathogenic protozoa and helminths (parasitic worms) are two other common microorganisms found in domestic sewage, the eggs of the latter being very difficult to eradicate. These as well as bacteria and virus are discussed at length in Module 9, "Pathogens".

The initial concentration of pathogens found in the influent of land application systems must be known to assess the resulting increase or decrease in populations found on the site. There is a direct relation between the health of the human population contributing wastes to a treatment system and the number of pathogenic organisms present in the system.

Potentially toxic elements found in municipal sewage include many substances which are also essential to microbial and plant life. Table 1 lists a few heavy metals found in trunk sewers collecting wastes from primarily residential areas (Davis, 1975). Commercial and industrial wastewater additions to municipal systems increase the variability in constituents by several orders of magnitude.

Municipal systems can be protected from inputs of toxic substances in high concentrations through pretreatment requirements leveled against commercial and industrial sources of wastes. Each situation is evaluated on a site-specific basis taking into account the industrial waste, the municipal treatment measures, and the receiving sink for the wastes. As industries implement these controls, it is likely that concentrations of toxics found in municipal wastewater will decrease. However, toxic substances in small amounts will always be present as long as metal pipes are used for home and commercial plumbing. Persistant organic chemicals such as PCB's enter the waste stream in substances used in the home as well as industrial point source discharges. These substances must also be classified as potentially toxic.

Wastewaters may contain many substances which can be toxic to plants or animals in sufficiently high concentrations. These potentially toxic elements may be treated by land application.

Table 3 lists two categories of toxic substances of concern in land application systems: 1) those most likely to cause toxicity to higher plants, and 2) those that have greatest potential for degrading ground water quality beneath land application systems. All of these substances are likely to be found in municipal wastes, and all respond to treatment in the soil. Various soil parameters affect its ability to immobilize potentially toxic substances. Monitoring and documentation of these toxic substances must be initiated for the waste influent, effluent, and, eventually, their buildup in the soil profile. Module 11, "Potentially Toxic Elements", discusses toxic elements at length. Module 18, "Monitoring at Land Application Sites" discusses this aspect of site operation in relation to potentially toxic elements.

## Flow Distribution and Pollutant Removals in Conventional Treatment Processes

The flow of wastewater and sludges as well as selected wastewater characteristics are shown in Figures 3 - 10. These diagrams outline the total amount of waste constituent entering each treatment process and depict how much of each is separated from the main flow of wastewater. These figures are drawn approximately to scale to enable the reader to estimate easily the efficiency of individual processes in controlling pollutants. The reader should relate the numbers given in each of the following figures to the composition of "strong, medium, and weak" wastewaters in Table 1, page 3. The percent removals and flows in the various processes are of importance in Figures 3-10, not absolute numbers.

Sludge removal in conventional treatment concentrates potentially toxic elements in the separated solids. Sludge handling accounts for 30-40% of conventional treatment costs.

The flow of wastewater and sludges shown in Figure 3 is based upon a wastewater design flow of 100 gallons per capita per day. Sludge removal in preliminary and primary treatment is less than 0.50% of the total waste flow whereas approximately 1% is separated out in secondary treatment. Examination of the flows in this figure illustrate the reason that toxic elements are more of a problem in the sludges than in the wastewaters. It will be shown in Module 11, "Potentially Toxic Elements" that a large fraction of the toxic elements are attached to the microbial mass and particulates removed during secondary treatment. The ratios of flow rates (inflow/sludge flow) are essentially concentration factors. Thus, any adsorbed material would increase its concentration 400 times in primary sludge and 100 times in secondary sludge. Further reductions in sludge volumes without the concomitant removal of the toxic elements will cause further concentration of the toxic elements. Advanced wastewater treatments can separate a substantial amount of the remaining solids, which may be contained in a relatively high portion of the waste flow, as shown in Fig. 3. These solids may then be separated and returned to sludge treatment.

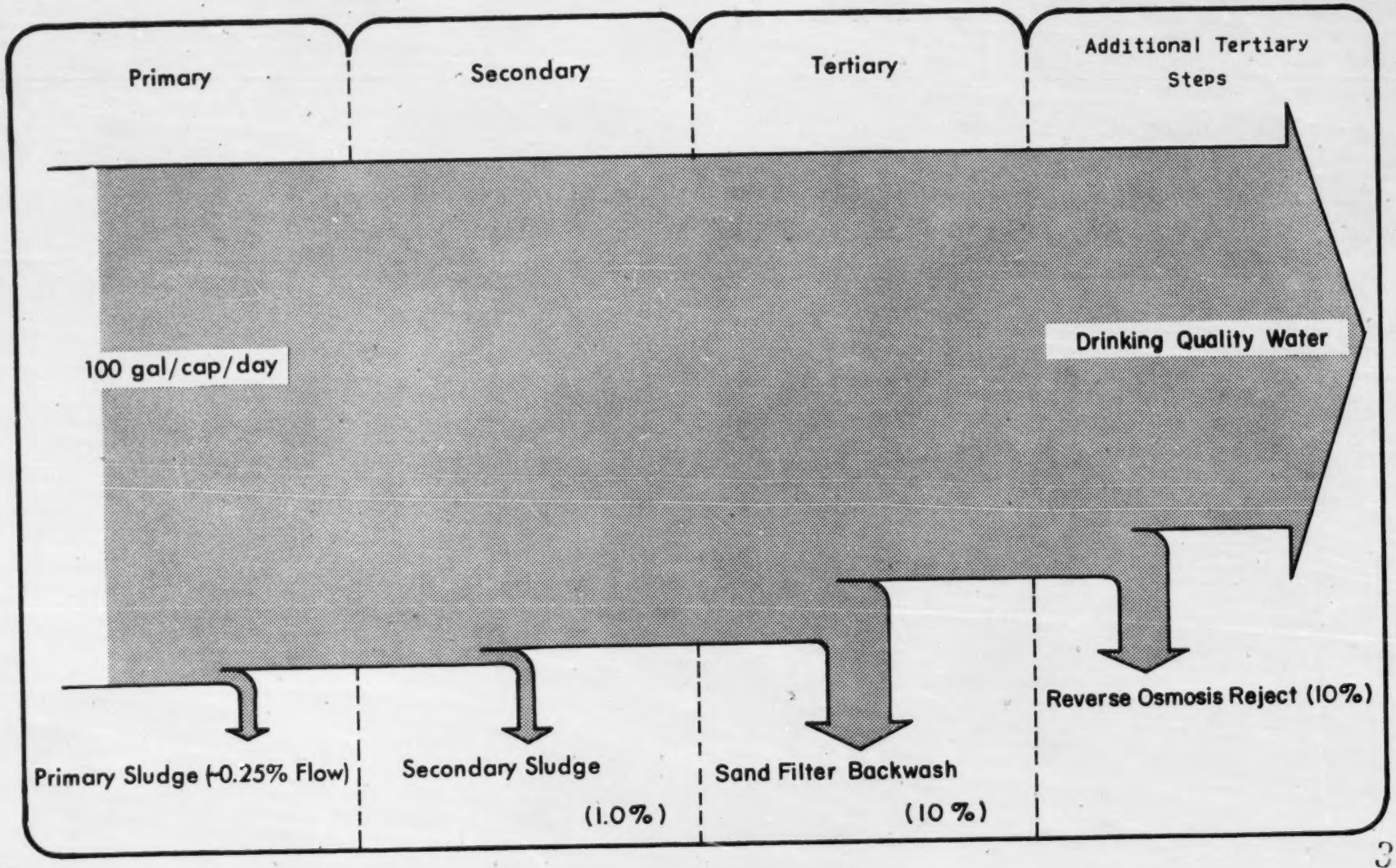


Figure 3. Flow distribution of wastewater & sludges through conventional and AWT processes

The cost of handling sludge in conventional waste treatment is approximately 30 to 40 percent of the total system. This cost can be minimized in land application systems by incorporating the solids into the soil profile during the treatment process.

Organics in conventional treatment, Figure 4, are almost entirely separated in primary and secondary treatment. Approximately 25% of the organic load in raw sewage is separated in primary sedimentation. Another 40% is utilized in microbial respiration of secondary treatment where $CO_2$, $H_2O$ and new microbial cell mass are the end products. The wasted microbial mass of secondary treatment accounts for another 20% of the total organic load. The effluent from secondary treatment carries with it approximately 15% of the original organic load. Tertiary treatment such as carbon adsorption can remove at least another 10% of the organics (based on original input quantity) leaving up to 5% of the input in tertiary effluent.

Suspended solids removal in conventional treatment, Figure 5, largely occurs during primary sedimentation. Approximately 60% of these solids are separated here. A high percentage of suspended solids are organic, as an investigation of the organics flow diagram, Figure 4, indicates. A portion of the organic solids are destroyed during microbial respiration in secondary treatment as described previously. Thirty percent of these solids are removed here, and approximately 10% are passed into receiving waters in effluents or on to tertiary treatment. Tertiary treatment may reduce this suspended solids content to as little as 2% of the original concentration.

A typical five day biological oxygen demand ($BOD_5$) of raw wastewater is approximately 250 mg/l, Figure 6. Primary sedimentation removes about 35% of this through organic suspended solids removal. The microbial processes of secondary treatment are designed to remove most of the remaining $BOD_5$, therefore it is not surprising that 50 to 60% of influent $BOD_5$ is removed in secondary treatment. The remaining 5-15% of the $BOD_5$ is passed on to tertiary treatment as soluble organics.

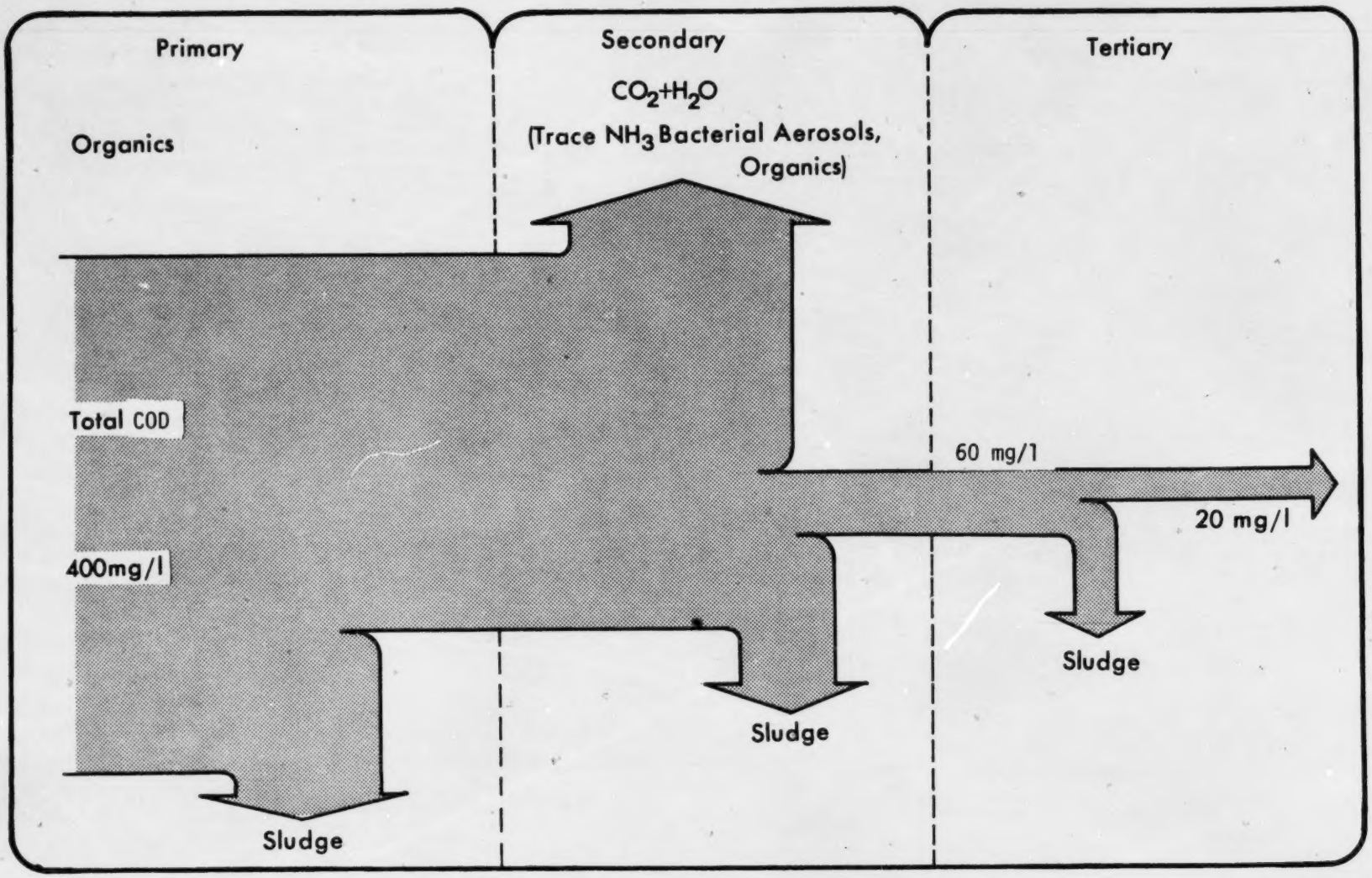


Figure 4. Fate of organics in conventional treatment and AWT processes.

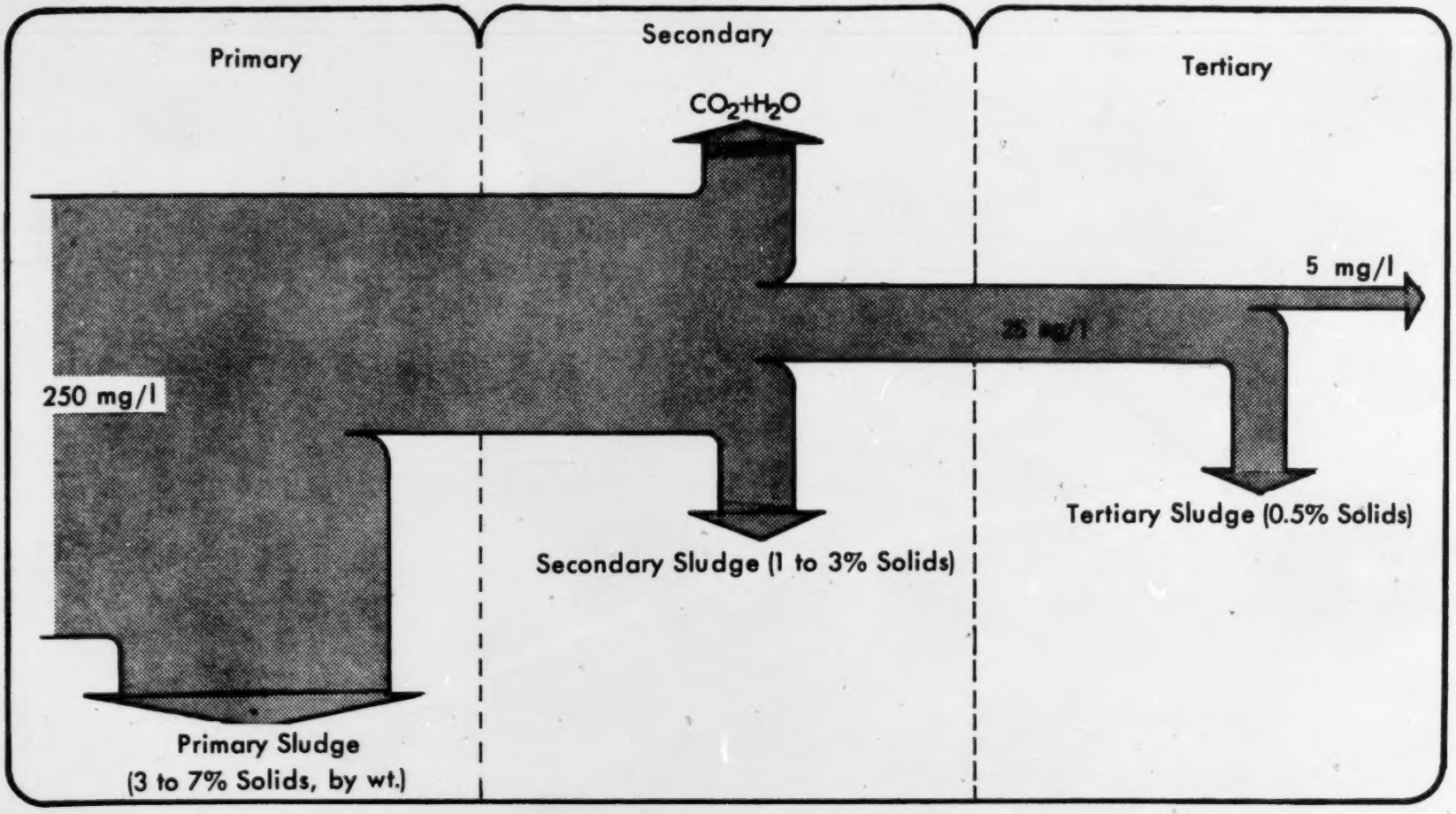


Figure 5. Fate of suspended solids in conventional and AWT processes.

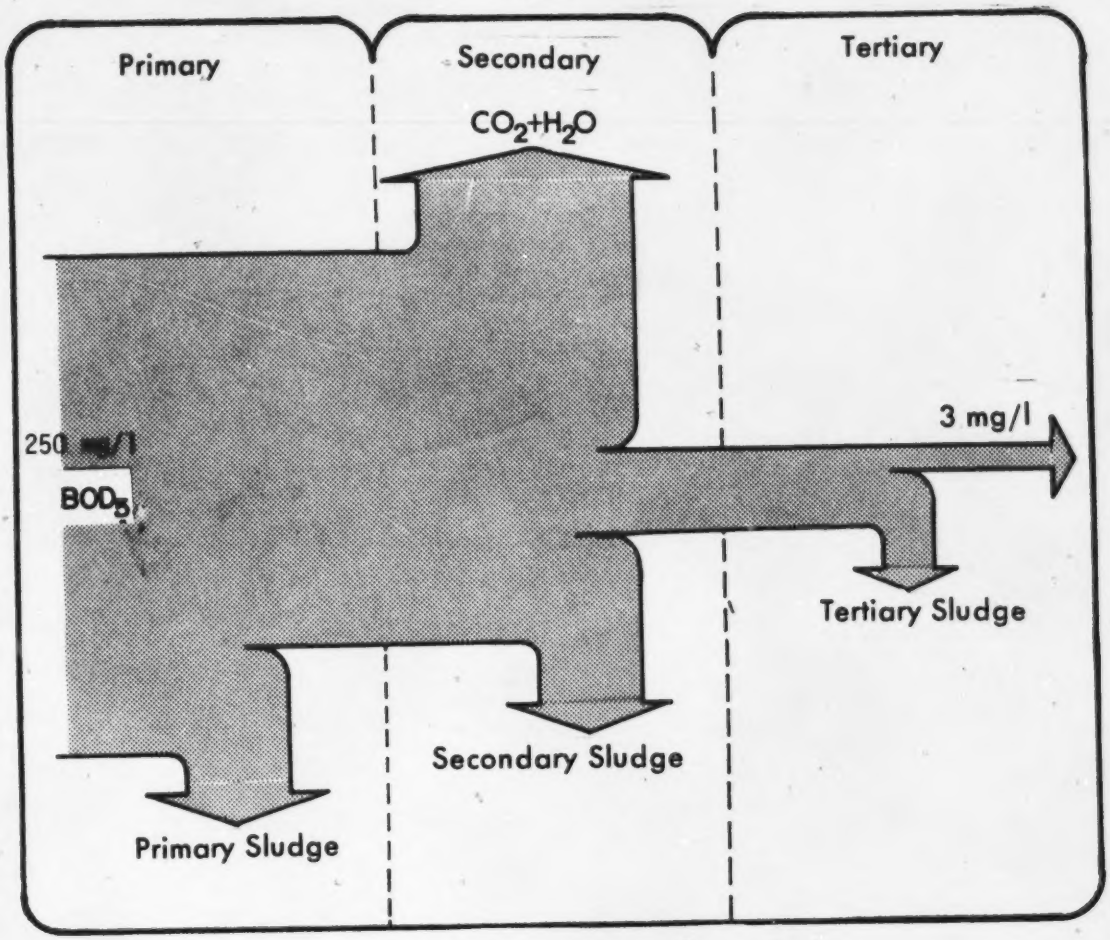


Figure 6. Fate of 5 day biochemical oxygen demand in conventional and AWT processes.

The total dissolved solids content of municipal wastewaters varies considerably. Figure 7 illustrates a low TDS concentration. As shown in this figure, preliminary, primary, and secondary conventional treatments do not remove these solids from the wastewater flow. Tertiary treatment processes have not attempted to remove these solids on a regular basis for to do so would be very energy intensive. However, reverse osmosis and distillation are two tertiary treatment processes which could remove dissolved solids. The recycle and reuse of domestic wastewater must overcome the cost of TDS removal, for each time water is used, the TDS content increases. Some tertiary treatment processes add chemicals which increase the TDS content of the wastewater while removing undesirable constituents, i.e., phosphorus precipitation, ion exchange.

Conventional tertiary treatment for phosphorus removal can increase dissolved solids content. There should be no change in TDS through secondary treatment.

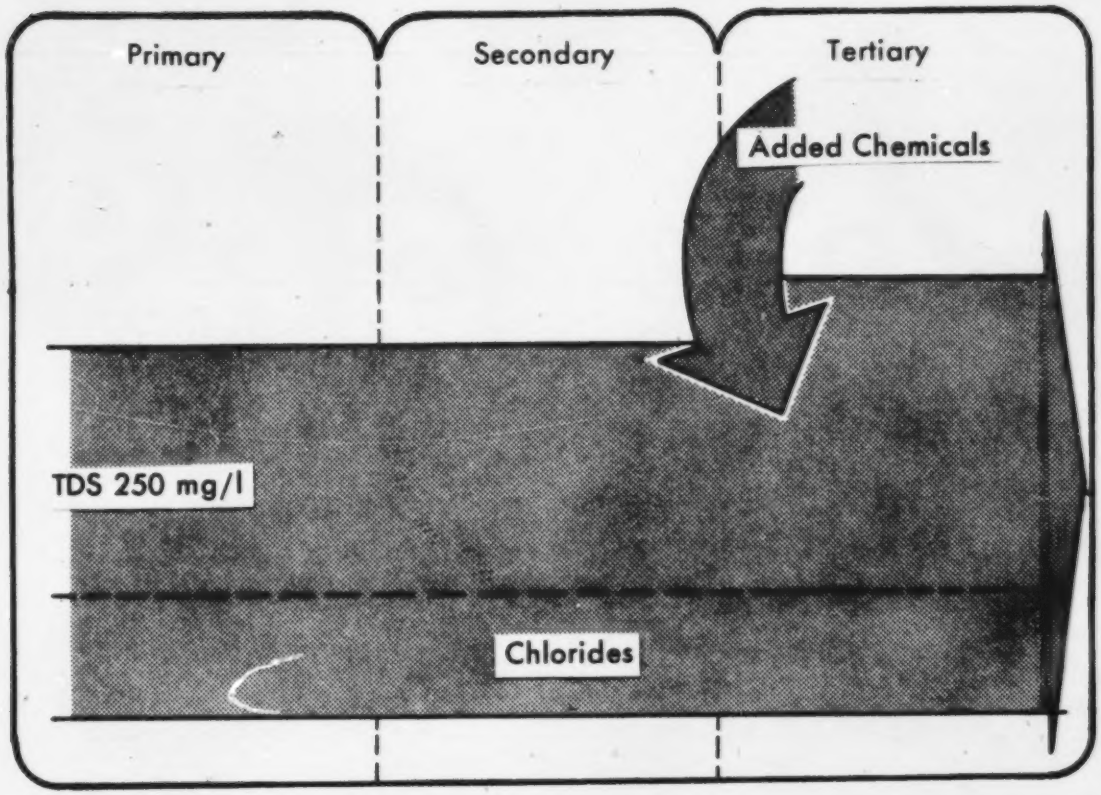


Figure '. Fate of total dissolved solids in conventional and AWT processes.

The total nitrogen found in raw domestic sewage varies between 15 and 60 mg/l, where 40-50 mg/l would be a typical amount. The fate of nitrogen in wastewater treatment is shown in Figure 8. Approximately 25% of this total nitrogen is separated in primary sedimentation as organic N. The microbial assimilation of organics in secondary treatment transforms organic nitrogen to ammonia and nitrate. In this process a small amount of nitrogen is driven off as ammonia and nitrogen gas. Still a smaller amount of organic nitrogen is wasted with the secondary sludge. Approximately 70% of the total nitrogen found in raw wastewater passes through primary and secondary treatment to tertiary treatment where

all but 2 to 6% can be removed using the microbial nitrification-denitrification process. The nitrogen concentration of tertiary effluent is mostly in the nitrate form where 1 to 3 mg/l might be expected.

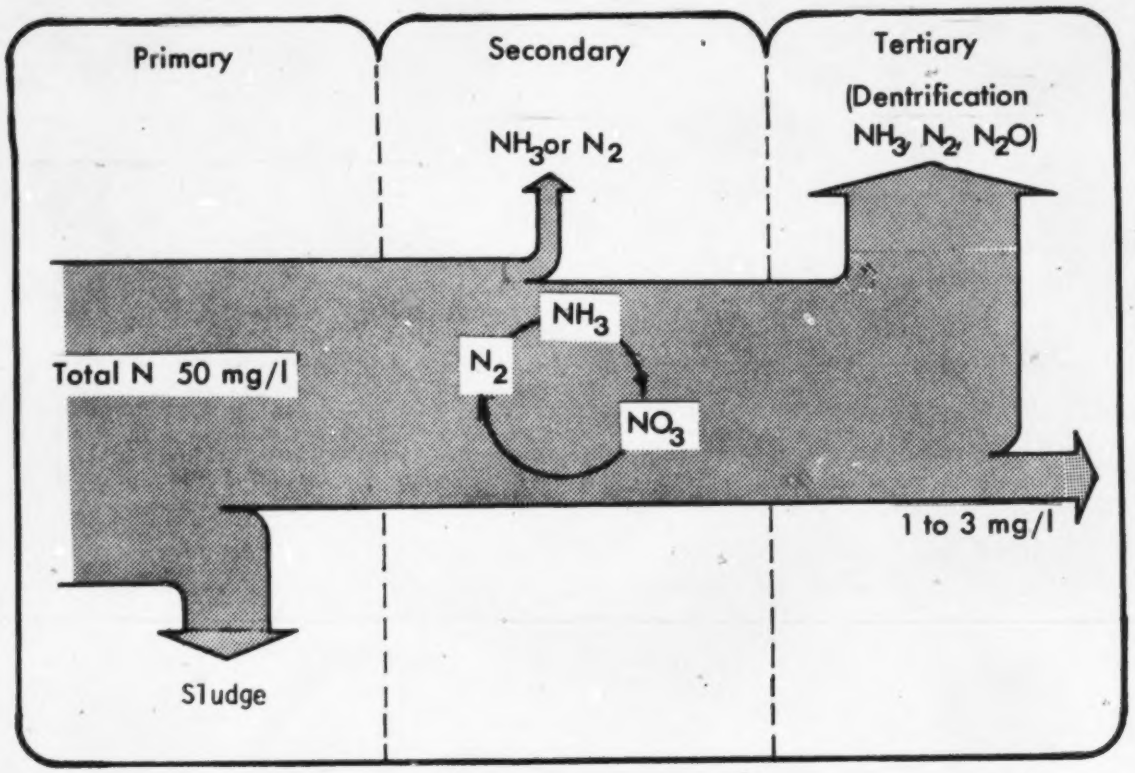


Figure 8. Fate of nitrogen in conventional and AWT processes.

Phosphorus removal in conventional and AWT treatment processes is shown in Figure 9. Approximately 1/3 of the total phosphorus is removed in preliminary and primary treatment through screening and sedimentation of suspended solids. Phosphorus removal in secondary treatment consists of the very small amount tied up in microbial cells which is wasted as sludge. However, tertiary treatments are available which will remove 80-95% of the total phosphorus influent. This is effectively accomplished within the primary sedimentation tanks where alum addition forces the phosphorus precipitation.

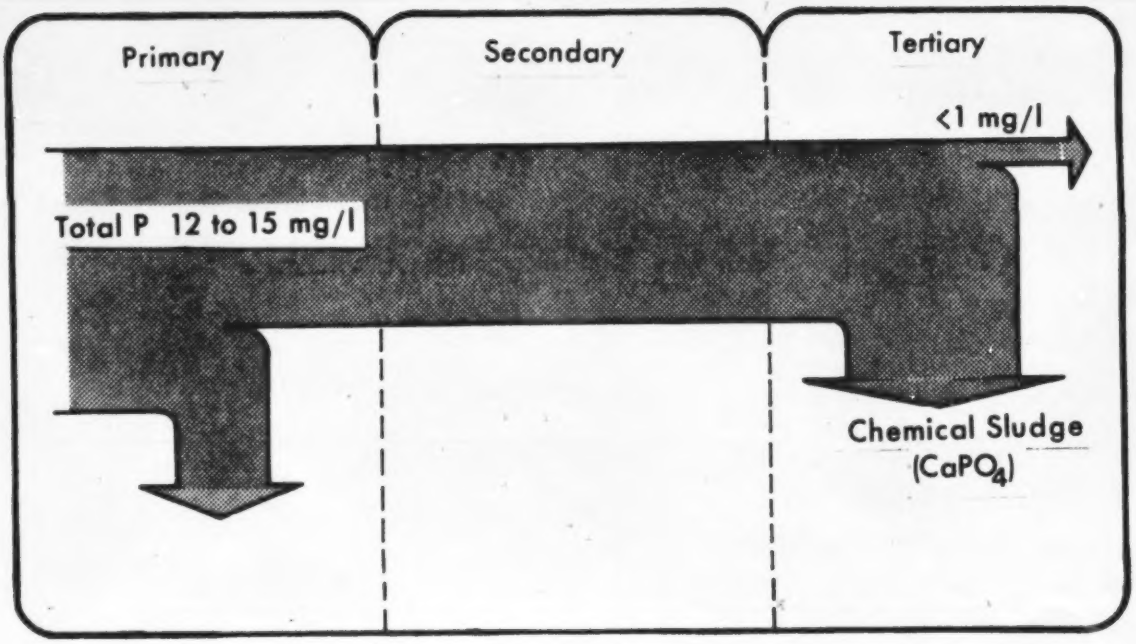


Figure 9. Fate of phosphorus in conventional and AWT processes.

The fate of toxics in conventional and AWT is shown in Figure 10. These toxics include heavy metals as well as other trace elements. Generally high concentrations of heavy metals are found in secondary and AWT sludges although the amounts are quite variable. As much as 80% of the potentially toxic substances are removed with secondary sludges whereas the remaining 20% is removed in tertiary sludges. Less than 1% of the incoming toxics are found in tertiary effluents. This illustrates the fact that potentially toxic elements are basically a sludge application problem rather than a wastewater application problem.

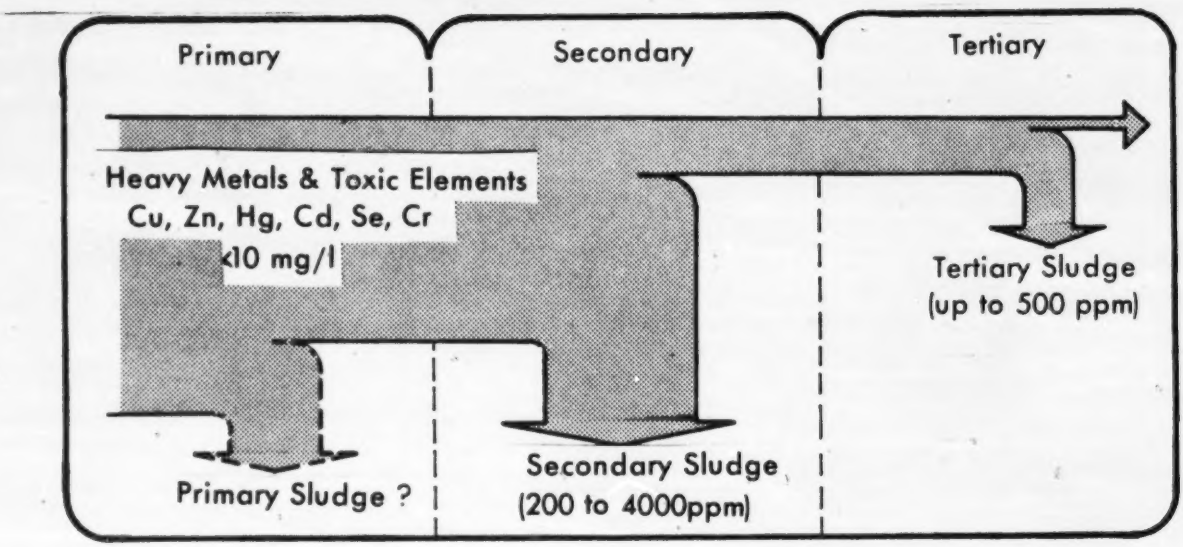


Figure 10. Fate of heavy metals and other potentially toxic elements in conventional and AWT processes.

## Sludge Characteristics

The properties of wastewater treatment residues which can be used in land application systems are highly variable. Sludge characteristics are a function of influent wastewater characteristics, treatment processes, and efficiency of the wastewater treatment. The form of sludge treatment, storage, and handling employed prior to land application will also affect its chemical and biological composition, and physical properties.

Characteristics of sludge for land application depend on influent wastewater characteristics, treatment processes and their efficiency, type of sludge treatment, storage and handling time before site delivery.

Sludges resulting from various treatment steps have distinct physical properties depending on their constituents and level of biological stabilization. Table 5 gives a comparison of typical sludges from conventional processes.

Table 6 gives some idea of the usual range and expected values of several chemical constituents of "typical" sludge. Nitrogen, phosphorus, and potassium are important to land application sites as nutrients. The other items listed indicate the relative degree of biological stability of raw and digested sludge, and the types of inorganics and resistant organics which are normally removed only through primary treatment (cellulose and silica). The variability of sludge components is reflected in the range of values for each chemical constituent. The figures in Table 6 are useful in preliminary design, but it is very important to analyze the sludge which will be applied in any given system.

Wide range of characteristics for a "typical" municipal sludge shows the variability of sludge composition. Emphasizes the need for analyzing sludge for each land treatment project.

Table 7 is a summary of actual laboratory analyses of sludge from 174 treatment plants in seven midwestern and eastern states (McCalla, Peterson, and Lue-Hing, 1977). Data on metals and salts discussed in Module 11, "Potentially Toxic Elements" and Module 20, "Crop Selection and Management Alternatives" are presented.

Table 5

General Physical Characteristics of Various Types of Sludge

| Sludge | Color | Other Physical Properties | Odor | Digestibility (Amenability to Further Biological Stabilization) |
|---|---|---|---|---|
| Primary Sedimentation | Gray | Slimy | Extremely offensive | Readily digested |
| Chemical Precipitation (Primary) | Black, red surface if high in iron | Slimy, gelatinous, gives off considerable gas | Offensive | Slower rate than primary sedimentation |
| Activated Sludge | Brown, dark if nearly septic | Flocculent | Inoffensive, earthy when fresh; putrifies rapidly | Readily digested |
| Trickling Filter Humus | Brownish | Flocculent | Relatively inoffensive, decomposes slowly | Readily digested |
| Digested Sludge | Dark brown to black | Contains very large quantity of gas | Inoffensive if thoroughly digested; Like tar or loamy soil. | Well stabilized |
| Septic Tank Sludge | Black | | Offensive ($H_2S$) unless very long storage time | Mostly stabilized |

Adapted from Metcalf and Eddy, 1972.

Table 6

Typical Chemical Composition of Raw and Digested Sludge

| Item | Raw Primary Sludge | | Digested Sludge | |
|---|---|---|---|---|
| | Range | Typical | Range | Typical |
| Total dry solids (TS), % | 2.0-7.0 | 4.0 | 6.0-12.0 | 10.0 |
| Volatile solids (% of TS) | 60-80 | 65 | 30-60 | 40.0 |
| Grease and fats (ether soluble, % of TS) | 6.0-30.0 | -- | 5.0-20.0 | |
| Protein (% of TS) | 20-30 | 25 | 15-20 | 18 |
| Nitrogen (N, % of TS) | 1.5-4.0 | 2.5 | 1.6-6.0 | 3.0 |
| Phosphorus ($P_2O_5$, % of TS) | 0.8-2.8 | 1.6 | 1.5-4.0 | 2.5 |
| Potash ($K_2O$, % of TS) | 0-1.0 | 0.4 | 0.0-3.0 | 1.0 |
| Cellulose (% of TS) | 8.0-15.0 | 10.0 | 8.0-15.0 | 10.0 |
| Silica ($SiO_2$, % of TS) | 15.0-20.0 | -- | 10.0-20.0 | |
| pH | 5.0-8.0 | 6.0 | 6.5-7.5 | 7.0 |
| Alkalinity (mg/liter as $CaCO_3$) | 500-1,500 | 600 | 2,500-3,500 | 3,000 |

Metcalf and Eddy, 1972

Table 7

Summary of Sludge Parameters from a Widespread Sample of Sewage Treatment Plants

| Constituent | | Number of Treatment Plants | Minimum | Maximum | Median | Mean | Coefficient of Variability, % |
|---|---|---|---|---|---|---|---|
| pH | | 61 | 5.3 | 11.7 | | | |
| Organic C | % | 101 | 6.5 | 48.0 | 30.4 | 31.0 | 27 |
| Total N | % | 134 | 0.0 | 17.6 | 2.5 | 3.2 | 85 |
| $NH_4$-N | % | 56 | 0.0 | 6.76 | 0.13 | 0.74 | 171 |
| $NO_3$-N | µg/g | 34 | 9 | 4,880 | 194 | 646 | 158 |
| Total P | % | 128 | 0.0 | 6.1 | 1.8 | 1.9 | 61 |
| Fe | % | 104 | 0.0 | 15.3 | 0.8 | 1.4 | 148 |
| Al | % | 83 | 0.1 | 3.5 | 0.4 | 0.5 | 119 |
| Na | % | 126 | 0.01 | 2.66 | 0.12 | 0.35 | 146 |
| K | % | 142 | 0.02 | 1.92 | 0.24 | 0.30 | 99 |
| As | µg/g | 10 | 6.0 | 230.0 | 10.0 | 43.1 | 171 |
| Mg | µg/g | 139 | 300 | 19,700 | 4,600 | 5,414 | 75 |
| B | µg/g | 60 | 4 | 757 | 28 | 109 | 162 |
| Zn | µg/g | 134 | 101 | 27,800 | 1,800 | 2,997 | 134 |
| Cu | µg/g | 131 | 84 | 10,400 | 850 | 1,308 | 138 |
| Ni | µg/g | 109 | 10 | 3,515 | 190 | 440 | 162 |
| Cr | µg/g | 119 | 17 | 99,000 | 906 | 3,280 | 309 |
| Mn | µg/g | 82 | 18 | 7,100 | 200 | 390 | 209 |
| Cd | µg/g | 115 | 4 | 846 | 20 | 101 | 157 |
| Pb | µg/g | 116 | 13 | 19,730 | 652 | 1,656 | 177 |
| Hg | µg/g | 53 | 1.0 | 10,600 | 6.0 | 1,077 | 232 |
| Co | µg/g | 15 | 1.0 | 18 | 4.0 | 5.3 | 83 |
| Mo | µg/g | 29 | 5.0 | 39 | 30 | 27.7 | 26 |
| Cd/Zn | % | 115 | 0.1 | 46 | 1.7 | 5.7 | 163 |

McCalla, Peterson, and Lue-Hing, 1977.

Module 11 points out the advantages and limitations of source control as a means of adjusting the level of metals which ultimately find their way to municipal sludge. One such program was instituted in Chicago in 1969, when the concentration of various elements which industries are allowed to discharge to the sewerage system was limited by ordinance. Table 8 compares sludge metal levels from 1969, 1972, and 1974 at a Chicago treatment plant serving a mixed industrial-municipal area. Although significant reductions in specific element levels can result from industrial source control, further reductions are difficult due to the contribution from domestic plumbing and the general urban environment.

Industrial source control is important in reducing metal content of sludge, but the effectiveness is limited by the amount of metals from domestic sources.

The approximate percentage removal of sludge constituents in conventional primary sedimentation, secondary activated sludge, and tertiary processes is indicated in the mass flow diagrams (Figures 3-10 of this module). This discussion is limited to conventional treatment of municipal wastewater. Consideration of specialized industrial wastes and other treatment processes would be too involved for this section. The designer must be familiar with the waste inputs and chemicals used in sewage treatment (i.e. alum added for precipitation, resulting in high sludge aluminum content) in order to provide for proper nutrient and potentially toxic element application rates for the specific situation at hand.

Table 8

Comparison of Metal Content of the Calumet Sewage Treatment Plant's Sludge
Before and After the 1969 Metropolitan Sanitary District's Sewage and Waste Control Ordinance
On Maximum Allowable Metal Concentration to the Sewer System

| Metal | Maximum Allowable Concentration In Incoming Sewage by MSDGC Ordinance | Sludge Source | | | Metal Reduction Ratio Before 1969:1974 |
|---|---|---|---|---|---|
| | | Lagoons | Anaerobic Digester | | |
| | | Before 1969[a] | 1972[b] | 1974[c] | |
| | mg/liter | µg/g dry-weight basis | | | |
| Cd | 2.0 | 190 | 100 | 54 | 3.5 |
| Cr (total) | 25.0 | 2,100 | 1,100 | 790 | 2.7 |
| Cu | 3.0 | 1,500 | 900 | 282 | 5.3 |
| Fe | 50.0 | 53,700 | 36,800 | 24,200 | 2.2 |
| Hg | 0.0005 | 3.3 | 3.0 | 2.15 | 1.5 |
| Ni | 10.0 | 1,000 | 200 | 77 | 13.0 |
| Pb | 0.5 | 1,800 | 1,800 | 486 | 3.7 |
| Zn | 15.0 | 5,500 | 3,500 | 2,800 | 2.0 |

[a]Mean of 10 samples

[b]Mean of 22 samples

[c]Mean of 6 samples

McCalla, Peterson, and Lue-Hing, 1977

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# WASTE CHARACTERISTICS

## Objectives

Upon completion of this module, the participant should be able to:

1. Characterize the physical, chemical, and biological properties of typical municipal wastewater.

2. Indicate the main effect of having a combined storm and sanitary sewer system on the characteristics of the waste.

3. Indicate three constituents of the influent that are of major concern in the design of land application systems.

4. Indicate the concentrations of the following after conventional primary, secondary, and advanced waste treatment levels for:

   a. organics - both $BOD_5$ and COD
   b. suspended solids
   c. nutrients
   d. pathogens and toxics

5. Compare these concentrations to those likely to result from a well managed wastewater application system.

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WASTE CHARACTERISTICS

Module 5

January, 1978

## WASTE CHARACTERISTICS

This unit concerns the characteristics of municipal and industrial wastes (Slide 1). The levels of treatment that can be expected from traditional and land treatment of waste are also described. The objectives of the unit are in the envelope marked "Objectives". Turn off the tape recorder and study the objectives before beginning this unit (Slide 2). You may keep the objectives for reference during the lesson.

When planning any waste treatment system it is necessary to understand the characteristics of the wastes and the provisions necessary for treating those characteristics (Slide 3). Variations in the characteristics of wastes arise from several different sources which can include the population size and industrial distribution; the combined storm and sanitary sewers; and even the source of the water supply. This unit will deal only with the constituents found in typical municipal wastewater and not the extremes that have been documented.

Slide 4 indicates the three major categories into which waste characteristics are usually divided. These are physical, biological, and chemical. Slide 5 shows typical physical characteristics for wastewater. The level of suspended solids is probably the characteristic in the list that is most used in descriptions. The untreated level of this parameter is the one that you should be especially aware of because it is the one characteristic that best describes the strength of domestic sewage.

The biological characteristics of waste are very important and are indicated in Slide 6. The total coliform concentration is an indication of the total bacterial level of the wastewater. The virus level is made up of several species of virus and is also important from a public health aspect.

The chemical characteristics of wastewater, shown in Slide 7, are very important when designing a treatment facility. These are the variables that will affect any chemical or biochemical reaction. Notice that most of the nitrogen is in the ammonia form and most of the phosphorus is in the inorganic form. The level of treatment and the fate of the chemical components of waste are critical for both conventional and land treatment.

Various methods have been devised to determine the organic content of wastewater. This figure (Slide 8) indicates the relationship among the various methods. The five day Biological Oxygen Demand, called 5-day BOD, is a measure

of the oxygen utlized by microorganisms in digesting the organics in the wastewater. This is measured over a 5-day period at 20°C and under controlled laboratory conditions. This amount is directly related to the biodegradable organics present in the wastewater. The other measures of organics indicated in this figure are also used. However, the 5-day BOD is the most commonly mentioned parameter.

The levels that have been shown indicate the normal levels that can be found in municipal wastewater. Variations that affect these levels include the type and concentration of industry (Slide 9) in relation to the population size and combined versus separate storm and sanitary sewers. Combined systems are the usual case in most older cities. The effect of a combined system is threefold as indicated in Slide 10. First, there is a great variation in water flow. Second, the increase in the water flow generally dilutes the concentrations of the previously discussed characteristics. Third, there is an increase in the level of suspended solids from a combined system. The average level of suspended solids from selected combined systems is about 410 mg/liter.

The remainder of this tape deals with flow distribution and treatment levels in conventional systems and land treatment systems. The two treatment methods will be compared. Keep in mind that the partially treated effluent from a conventional system is often the influent to a land treatment system. The conventional system we will consider is shown schematically in Slide 11. It consists of a preliminary screening and grit removal, primary settling, secondary biological treatment, and advanced waste treatment (Slide 12). The method of land application that will be considered, indicated in Slide 13, is an irrigation system with preliminary treated wastewater applied 2" per day one day per week, 50 weeks a year. Slide 14 indicates the flow to this site per acre and the amounts of potential pollutants that are applied. As Slide 15 shows, suspended solids are mainly removed in primary sedimentation in a conventional treatment system. The organic portion of the remaining suspended solids are degraded in secondary treatment through microbial action. Approximately 10% of the level of the influent suspended solids are sent on to tertiary treatment or into receiving waters in systems in which there is no tertiary treatment. Tertiary treatment can reduce the suspended solids to as little as 2% of the original level.

Land application, also shown in Slide 15, is very effective in treating suspended solids when aerobic conditions are maintained. Much of the suspended solids are organics and are treated like other organics. Almost all of the suspended solids are filtered out in the first few inches of soil. In our system, used for this comparison, we are adding about six thousand pounds of suspended

solids to an acre per year. This must be considered against the background level of about eight million pounds of soil per acre two feet. The soil's efficiency in removing suspended solids is better than 98% for even much higher loads (Slide 16).

A typical five day biological oxygen demand of raw wastewater is about 250 mg/l, as Slide 17 indicates. Primary sedimentation removes about 35% of this in conventional treatment. The microbial processes of secondary treatment are designed to remove this BOD, and 65 to 85% of the remaining BOD is removed in these processes for an overall removal of 80-95%. The remaining 5 to 20% is passed into the receiving water or onto tertiary treatment. The approximately 25 mg/l that enters tertiary treatment, however, is not the same organics that entered the treatment plant. Secondary treatment, although it degrades the influent organics, adds its own organics to the effluent as a by-product. In fact, the mass flow diagram could be changed as in Slide 18.

In land treatment about six thousand pounds of BOD a year is being added to a reserve of about 100 tons of background organics in an acre two feet. The microbial activity of the soil can treat this and even much higher levels of BOD at greater than 98% efficiency as indicated in Slide 19. Normal respiration and oxidation in the soil will prevent accumulation of organic matter and soil clogging.

Slide 20 shows the removal of phosphorus in our sample conventional and land treatment systems. Although about one-third of the phosphorus is separated out in primary sludge, the main removal mechanism is chemical precipitation by the addition of alum or lime in advanced waste treatment. This treatment is quite effective, giving less than 1 mg/l in the effluent. This process, however, generates a significant amount of sludge. Land application and treatment of phosphorus is from 97 to 99% effective. The phosphorus added to the soil is taken up by vegetation or participates in several reversion reactions which tend to make it unavailable for plants or leaching. This situation holds true even for levels of phosphorus much higher than used in our example.

Approximately seventy percent of the total nitrogen passes through primary and secondary treatment. As Slide 21 indicates twenty-five percent is separated in primary sedimentation as organic N and five percent is driven off as ammonia and nitrogen gas or wasted with the secondary sludge in our sample system. Tertiary treatment for nitrogen in this system consists of biological

nitrification and denitrification under anaerobic conditions. After this tertiary treatment, 2-6% of the total N is passed into the receiving water.

Nitrogen is often a limiting factor in the land application of wastewater. Much of the added nitrogen is lost as ammonia, nitrous oxide or nitrogen gas. A harvested crop, like reed canary grass (Slide 22), will use from 200 to more than 400 pounds of nitrogen a year. Land application systems should be designed and carefully managed so that a leaching of less than 10 mg/l as nitrate-nitrogen can be expected.

Toxics, which include heavy metals as well as trace elements, are removed in secondary and tertiary sludges, although the amounts are quite variable (Slide 23). Less than 1% of the incoming toxics remain in tertiary effluents. This, of course, moves the problem of toxics from the wastewater to the sludges, where they are very concentrated. The treatment of sludge will be dealt with later in this presentation.

As long as toxics or heavy metals are present in normal levels in the sewage and the site is well-designed and managed, they present no problem in land application. Toxic elements in municipal sewage include many substances which are essential to microbial and plant life in low concentrations. The table in Slide 24 lists two categories of toxic substances that in high concentrations are likely to become toxic to plant life or will tend to degrade the groundwater. Module 11, "Potentially Toxic Elements", discusses toxic elements at length.

The total dissolved solids content of municipal wastewaters varies considerably. These solids are mainly dissolved salts. As is shown in Slide 25, conventional treatments do not remove these solids from the wastewater flow. Tertiary treatment processes have not attempted to remove these on a regular basis for to do so would be very energy intensive. The recycling and reuse of domestic wastewater must overcome the cost of TDS removal, for each time water is used, the TDS content increases by approximately 500 mg/l (Slide 26). Some tertiary treatment processes in our sample system add chemicals which increase the TDS content of the wastewater while removing undesirable constituents, for example, phosphorus precipitation.

In land treatment the TDS content of wastewater is of interest because of its effect on drinking and irrigation water (Slide 27). The Public Health Service has set a preferable limit of 500 mg/l on the total dissolved solids content of drinking water but the concentration of only specific inorganic constituents are recommended in the EPA's most recent standards.

A high TDS level in irrigation water can cause a saline or alkaline soil through the concentration of salts in the root zone (Slide 28). This usually is a problem only in arid areas where the evapotranspiration rate is high. This build-up of salts in the soil can affect both crop production and the soil characteristics itself. This problem can be avoided through careful management which might include a leaching factor in the irrigation water requirements. Even with the inclusion of a leaching factor, however, there will be a concentration of the TDS level because of the evapotranspiration of the irrigated water. This concentrated soil solution will pass through into the groundwater if water for leaching has been included. As can be seen from Slide 29, the conductivity of wastewater ranges from about .39 to about 1.33 mmhos/cm at 25°C, which is comparable to many irrigation waters presently used in the irrigated west.

In fact, there is essentially no treatment for dissolved solids in either conventional or land treatment (Slide 30).

Conventional primary, secondary, and advanced waste treatment produce a great volume of sludge containing an array of plant nutrients and toxics (Slide 31). Each of the conventional removal processes outlined in this module results in additions to the sludge and sludge characteristics. Of course, the sludge characteristics are highly variable depending upon the processes used and the pollutant characteristics of the incoming wastewater. Slide 32 is a photograph of the extensive sludge produced in one type of conventional treatment. With careful management, municipal sludge can be successfully incorporated in a land application system. Slide 33 shows one crop that is being grown with the aid of sewage sludge. The table in Slide 34 indicates the characteristics of sewage sludge that are of concern currently in land application systems. Other toxic substances must also be investigated in future land application systems. These are the contaminants as outlined in the National Interim Primary Drinking Water Regulations, and discussed in Module 1 concerning the legal and social aspects of land application of wastes.

This has been a brief review of the characteristics of waste and the treatment levels that can be expected with conventional and land treatment systems. The other modules in this Program discuss the treatment of individual waste characteristics in much greater detail.